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AGRICULTURAL MEMORANDUM NO. 353

The Effects of Soil Moisture and Temperature on the Germination of Maize

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Introduction

In Agricultural Memorandum 341 an index for sowing to emergence based on temperature only was tried with lack of success. An attempt to improve matters is now made by:

1. Accumulating 2" soil temperatures above 50°F rather than 46°F as previously. Maximum and minimum soil temperature values available on a daily basis.

2. Allowing for soil moisture by reckoning as zero any temperature accumulations after 3 consecutive dry days during sowing to emergence.

3. Estimating soil moisture deficits during germination and relating these to accumulated soil temperature and number of days from sowing to emergence.

1. Accumulated Soil Temperature Above 50°F. Linear Model

Values of accumulated soil temperature above 50°F were found for each day during sowing to emergence using M.O. Form 3300, and totalled. The same 8 years data is used as in Agricultural Memorandum 341.

Mean value = 93.1°F days. Extreme range = 72°F-days (124 to 52).

Range/Mean = 77.3%.

This is to be compared with a variability of 59% for a base temperature of 46°F. However, difficulty in comparing the two values arises due to the reduction in Range/Mean ratio as the base temperature for accumulation decreases. This happens apart from any other effects that might be occurring.

An alternative way of checking which base temperature is correct is to determine the skewness of the distribution of accumulated temperature. Positive skewness indicates that the threshold temperature is too low and vice versa. The results for a base temperature of 46°F indicate positive skewness, and for a base of 50°F the distribution is less skewed, while for base 53°F it is negatively skewed.

Base 46°F	Mode = 142	Mean = 149
Base 50°F	Mode = 91	Mean = 93
Base 53°F	Mode = 65	Mean = 60.7

This would indicate that a base of 50°F is nearer the true threshold, but this is based on a sample of 16 numbers only.

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2. Allowing for 3 Dry Days

In this method it is assumed that the soil at seed depth is too dry for germination to proceed after 3 consecutive dry days, and the accumulated temperature for these days is reckoned as zero, as are subsequent days until measurable rain falls.

Linear Model, base temperature 50°F. Mean 73.5°F-days. Extreme range 72°F-days (124 to 52). Range/Mean = 106%.

Parabolic Model, base temperature 46°F, optimum 80°F. Mean = 96.3. Extreme Range = 106.6. Range/Mean = 110.7%.

No improvement is found and so a more detailed water balance was attempted.

3. Estimation of Soil Moisture Deficits During Germination

The problem is to estimate evaporation from bare soil. Eagleson, 1970 suggests that for air relative humidities below 99% this depends upon the type of soil (structure, degree of compaction). In order to simplify matters however, the following scheme is used (Smith, 1958).

1. Evaporation occurs at the potential rate from field capacity to 12 mm. moisture deficit.

2. From 12 mm to 25 mm evaporation at 1/5 the potential rate.

3. Any rain which falls is assumed to evaporate at the potential rate.

Example. If at the start of a day the deficit was 6.0 mm and there was 1.0 mm of rain, but 2.5 mm of potential evaporation. Then all the rain would be evaporated, plus 1.5 mm from the soil. Deficit at end is 7.5 mm.

If the deficit were 13.0 mm to begin with, then 1.0 mm goes at the potential rate as before, but the next 1.5 mm at 1/5 the potential rate. Thus deficit at end is 13.3 mm.

Potential transpiration was estimated on a daily basis using Penman (MAFF, Technical Bulletin No. 16). The terms involving long-wave radiation and atmospheric vapour pressure and wind speed were assumed to cancel, and so sunshine hours (measured at the Radcliffe Observatory, Oxford) and mean temperature (at trial grounds, Wytham) were the only variables used. An albedo of 0.15 was assumed - a mean of values quoted for bare soil. Errors of up to 30% in the absolute value of daily evaporation seem likely, but due to the large systematic component (about 15-20%) relative values should be more accurate. Rainfall was also obtained from Radcliffe, which would introduce further errors into the calculation of soil moisture deficit, but a systematic component would also be present here too.

(a) Accumulated Temperature and Soil Moisture Deficit. (Figure 1)

In the graph accumulated two inch soil temperature above 50°F is plotted against the mean soil moisture deficit from sowing to emergence. The required accumulated temperature increases as the soil becomes drier. The

/regression

regression line is:

$$A = 4.88S + 41.27$$

(correlation coefficient is 0.82, significant at P = 0.001).

A is accumulated temperature, S is mean soil mosture deficit from sowing to emergence.

According to this, the least accumulated temperature necessary(i.e. for S = 0) is 41.27 $\pm$ 13.8 °F-days. The error in this figure is the standard error of estimate. No allowance for systematic errors is made in the figure 41.27, and the true value could differ by 20% from this. Some of the scatter of the points in the graph may be explained by differences in rainfall between Wytham and Radcliffe. For example the point 1964 (2) should be more to the right, in a drier regime, since several heavy showers occurred at Radcliffe and the evidence is that Wytham may have missed one.

An allowance for the effects of soil moisture on accumulated temperature can be made from figure I, by reducing the values of accumulated temperature relative to the value at which S is zero. The corrected value is obtained from:

$$\text{Corrected accumulated temperature} = \text{Actual accumulated temperature} \times \frac{41.27}{4.88S + 41.27}$$

Thus if every point lay on the regression line, all the corrected values would be 41.27. The coefficient of variation (standard deviation divided by the mean) was 26% for the original data, but is reduced to 16% when the moisture correcting factor is applied.

Bierhuizen (1970) reported that the accumulated temperature requirements from sowing to emergence were related to the soil moisture conditions during the five days after sowing. He found that the accumulated temperature was nearly constant for low soil moisture tensions, from pF 2.0 up to about pF 2.6, above which a sharp increase in the required accumulated temperature occurred as the tension increased. Water-logged conditions also increased the required accumulated temperature.

This relation was examined here and figure 2 shows accumulated temperature (sowing to emergence) plotted against the mean soil moisture deficit during the five days after sowing. A check for waterlogged conditions showed that 1964 (2) and 1966 (1) were probably affected and are omitted in what follows. The remaining points show a relation very similar to Bierhuizen's with a small increase up to about 8 mm deficit followed by a large increase in accumulated temperature above this value. Attempts to fit curves to the data were made by assuming an exponential or parabolic relation. The fitted curves are:

Exponential $A = 39.7 \exp (0.067 S')$

Correlation coefficient is 0.84. Significant at P = 0.001

Parabolic $A = 0.27 S'^2 + 48.0$

Correlation coefficient is 0.82. Significant at P = 0.001.

/A

A is the accumulated temperature above 50°F, and S' is the mean soil moisture deficit (mm) during the five days after sowing.

Thus both relations fit the data equally well and differ mainly for large and small S'. The parabolic form would appear to behave more sensibly for small S' and also gives a larger gradient for large S' than the exponential.

The predicted accumulated temperatures for field capacity are:

39.7 ± 12.7°F-days (exponential)

48.0 ± 14.8°F-days (parabolic)

These values lie within the range of each other and also within the range given by the linear regression in figure 1.

(b) Number of days (sowing to emergence) and temperature (figure 3)

If a constant accumulated temperature were required for sowing to emergence then a plot of time against mean accumulated temperature would be an hyperbola.

i.e. if $\Sigma (t - 50) = k$

(where t = temperature °F, k = constant).

Then $D = \dfrac{k}{\Sigma \frac{(t - 50)}{D}}$. D is the time in days between sowing and emergence.

In figure 3 which shows D plotted against $\Sigma (t - 50)/D$ a smooth curve is not obtained, particularly between D = 20 and 22 days.

However, if accumulated temperatures modified according to moisture as in section 3(a) above are used then it is possible to draw a smooth curve through the points (figure 3).

In this case then:

$$D = \frac{k'}{C \Sigma \frac{(t - 50)}{D}}$$

Where k' is another constant and the moisture factor $C = \dfrac{41.27}{4.88\ S + 41.27}$

Chirkov (1965), found similar relations using direct measurements of soil moisture.

Conclusion

Drying out of the soil increases both the required accumulated soil temperature and the time needed from sowing to emergence. Since it is

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important to allow maize plenty of time for the grain filling and ripening stage, the germination and vegetative stages have to be as short as possible. The results here show that even with the soil at field capacity, 40 to 50°F-days are required for germination and in a warm Spring implies about 5 days for emergence. Dry conditions combined with cool temperatures are bad, possibly with over a month required for emergence. Figure 2 shows that a critical factor in germination is the soil moisture status at seed depth in the few days immediately after sowing. Moist (but not waterlogged) soil at this stage appears to reduce the required accumulated temperature for sowing to emergence.

Any comments or suggestions on this paper should be sent to the author.

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Figure 1 Relation between accumulated two inch soil temperature above 50°F and soil moisture deficit from sowing to emergence

64(2) Year and sowing number

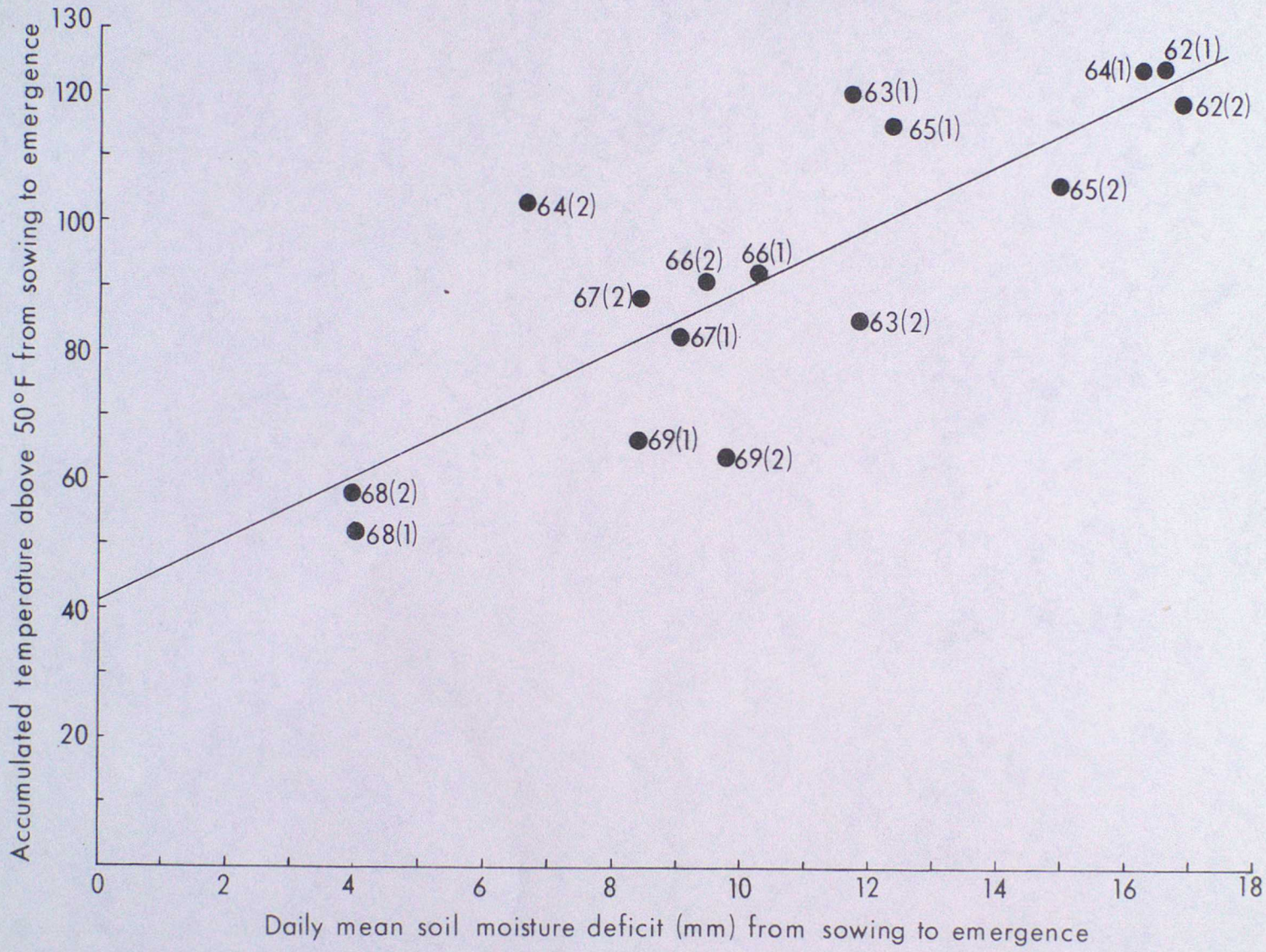

Figure 2 Accumulated two inch soil temperature from sowing to emergence plotted against the mean soil moisture deficit during the five days after sowing

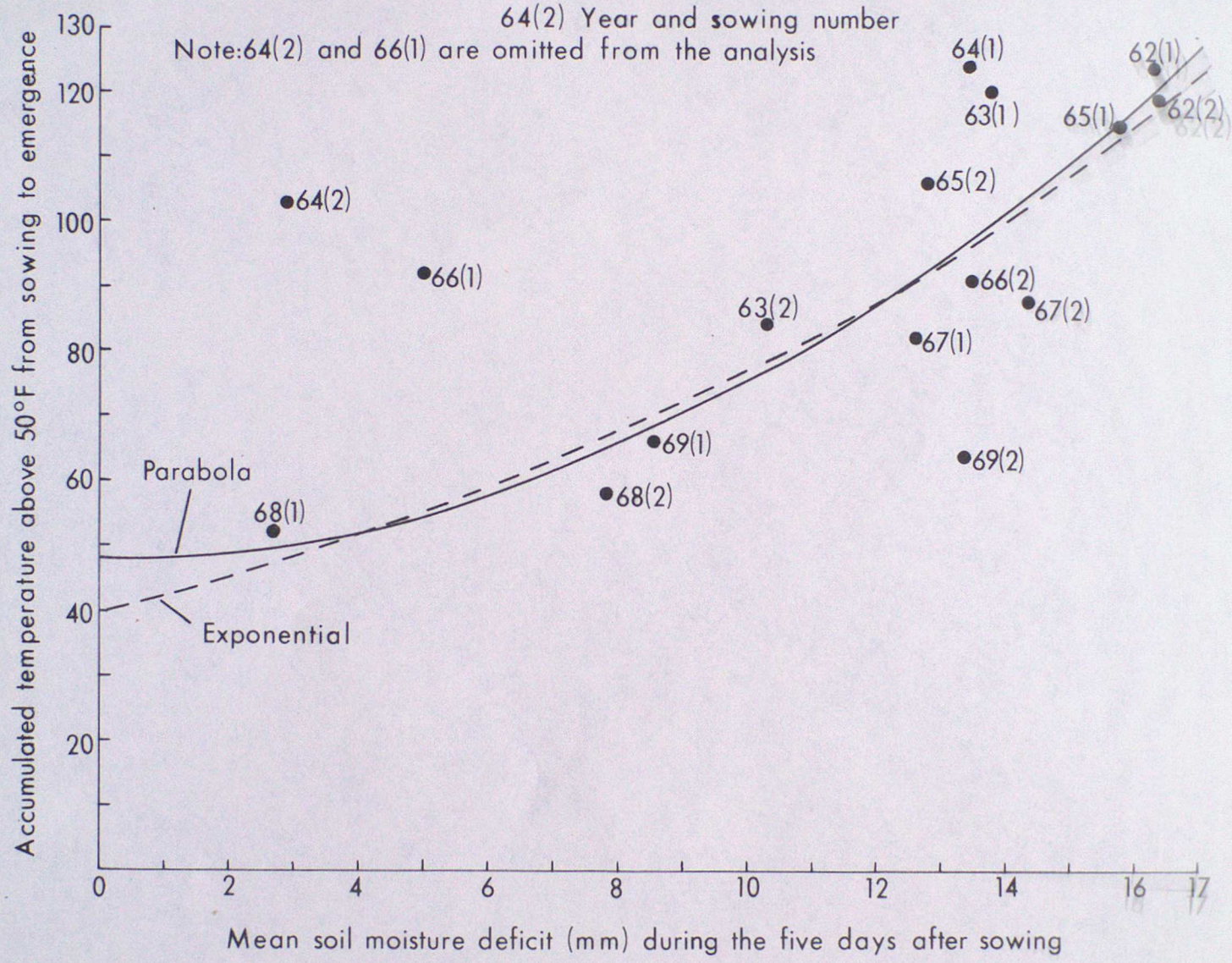

Figure 3 Relation between the number of days between sowing and emergence and the mean accumulated temperature above 50°F

× Unmodified temperature
● Temperature modified according to soil moisture deficit (drawncurve)